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Shielding Design Study of the Demonstration Fast Breeder Reactor (1)
- Evaluation of the JASPER Experiment and Its Analytical Results -

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The JASPER Experiment had been conducted to obtain useful information on FBR shielding analysis accuracy. Results obtained from the post-experimental analyses are summarized in this paper. Both characteristics for bulk shielding attenuation and streaming of neutron through configurations consisting of several materials including B_4C, stainless steel, sodium and etc. were clarified and the analysis accuracy confirmed. The shielding analysis system for fast reactors has been improved and verified. These experimental data and analytical results were reviewed from a viewpoint of the applicability to the shielding design analysis of the DFBR. Useful information to be utilized in the design study of the DFBR is accumulated through those activities.

KEYWORDS: FBR, Tower Shielding Facility (TSF), neutron streaming, boron-carbide, sodium, stainless steel, bulk shield, DOT3.5, TORT, DORT, MORSE

I. Introduction

Developing high performance shielding material and improving the accuracy of shielding analysis were the problems to be solved for cost reduction and optimization of the Demonstration Fast Breeder Reactor (DFBR). In order to solve these problems, the JASPER[1, 2], Japanese-American Shielding Program for Experimental Research, had been conducted between 1986 and 1992 under the cooperation between the U.S. Department of Energy and Power Reactor and Nuclear Fuel Development Corporation of Japan (PNC, present Japan Nuclear Cycle Development Institute).

The objectives of the program are to obtain useful information for resolving the problems on the DFBR shielding design and to improve the accuracy of shielding analysis by the evaluation and improvement of nuclear data and calculation codes through the experiment analysis.

In this paper, analytical results are summarized focusing on the particular experiments directly applied to the shielding design study of the DFBR among the JASPER experiments. Outline of the experiment and analytical method are presented first, shielding characteristics and analytical accuracy next, and the experimental data and analytical results are reviewed finally from a viewpoint of the applicability to the shielding design analysis of the DFBR. Detailed information for the analysis is presented in some other papers[3-5].

II. Outline of JASPER Experiment

All eight experiments were performed in the JASPER program. The JASPER experiments and those objectives are summarized in **Table 1**. All the experiments were performed using Tower Shielding Facility (TSF)[6] of Oak Ridge National Laboratory. The experimental configurations as shown in **Fig.1** began with Spectrum Modifier (SM) followed by shield mockups. The neutron source was generated in the TSR-II placed in its Big Beam Shield that collimated neutrons leaving the reactor into a horizontal beam. The mockup slabs were centered on this horizontal beam and surrounded by lithiated paraffin and concrete to reduce the background contribution.

Five types of detectors were used for measurements. Bonner balls were used most frequently of the all detectors, because the measurement time is relatively short and energetically separated data can be obtained to some extent. Total

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Table 1 JASPER experiments and those objectives

Experiment	Objective
Radial Shield Attenuation	Investigate neutron transmission through benchmark assemblies and representative mockups of radial shield designs
Fission Gap Plenum	Verify predicted neutron streaming effects in the fission gas plenum region of LMR-type fuel assemblies.
Axial Shield	Investigate the effectiveness of different geometric designs and alternative materials for LMR axial shield designs.
In-Vessel Fuel Storage (IVS)	Determine source multiplication and 3-dimensional effects of in-vessel stored fuel.
Intermediate Heat Exchanger	Study activation rate distributions within intermediate heat exchanger (IHX) mockups.
Gap Streaming	Investigate neutron streaming in planar and annular gaps which are representative of inter-component spacings in the
Flux Monitor	Optimization of Neutron Instrumentation System (NIS) Location.
Special Material	Confirmation of Shielding Characteristics of Zyrconium-Hydride (ZrH1.7).

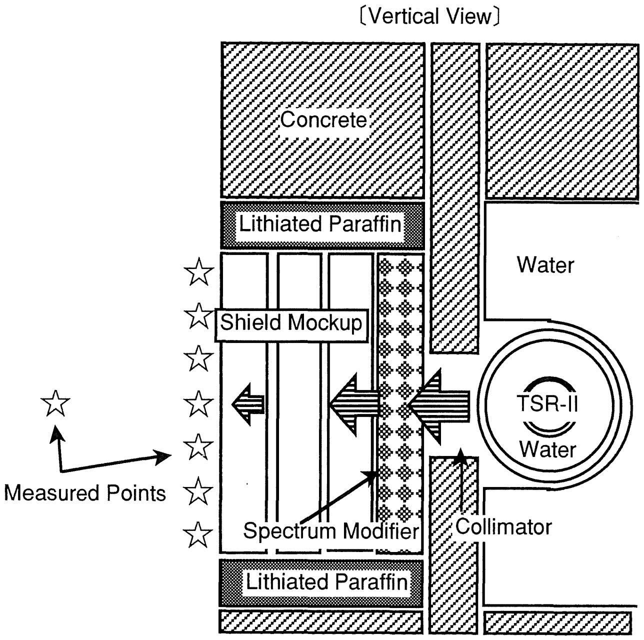


Fig. 1 Conceptual JASPER measurement configuration in TS

measurement error is within 10 %, which is mainly caused by the uncertainty of the TSR-II reactor power.

III. Analysis Method

Analysis was performed based on standard shielding calculation method of FBR in Japan. Fundamental flow of JASPER analysis is illustrated in **Fig.2**.

JSDJ2[7] cross section library generated from JENDL-2 file[8] was applied to the analysis instead of JSD100[9] library from ENDF/B-IV which was conventionally used. It is by the reason why the JSDJ2 gives better agreement with measured data than JSD100 after penetrating various materials covering wide energy range[3].

100-energy-group effective macroscopic cross sectic edited using RADHEAT-V3 code system[10]. Then, one-dimensional Sn calculations with the 100-group cross section were performed to obtain regional neutron spectra, which are weighting function to collapse the 100-group cross section to 21-group cross section. The 21-group cross section was applied to multi-dimensional transport calculations.

Two-dimensional Sn code DOT3.5[11], standard code in FBR shielding analysis was mainly applied in the analysis, and used

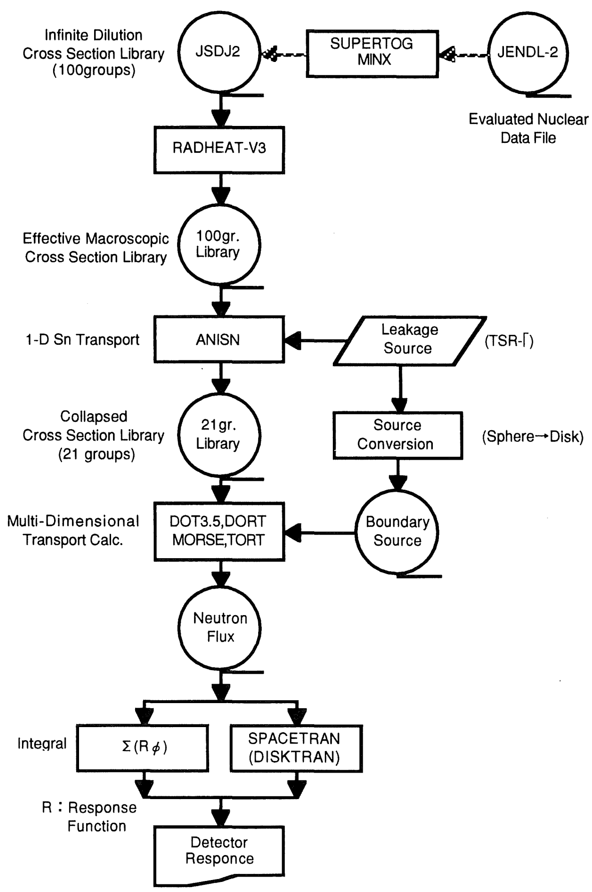


Fig. 2 Schematic flow diagram for JASPER experimental analysis

were also two-dimensional Sn code DORT[12], three-dimensional Sn code TORT[12] and three-dimensional Monte Carlo code MORSE[13] in correspond to the analysis objective. The detector responses behind mockups were evaluated using the angular fluxes behind configurations with SPACETRAN code[14] for the analysis of bulk shield penetration and with DISKTRAN code[15] for the streaming analysis, respectively.

IV. Results

Summary of the experimental data and analytical results which are directly related to the shielding design study of the DFBR, are presented as follows.

1. Radial Shield Attenuation Experiment

Bulk shielding characteristics had been obtained for B_4C, graphite, and stainless steel (SUS) by the radial shield attenuation experiments. Adding the data for sodium from the ORNL sodium benchmark experiment[16], comparison of neutron attenuation performance and its prediction accuracy was made among these shielding materials important for FBR's.

The attenuation performance was compared in **Fig. 3**, using the experimental results of Bonner ball responses. In the figure, the response is normalized at the inner surface of each material by each Bonner ball. The figure shows that B_4C requires only the one-third thickness of stainless steel to realize same attenuation performance. Considering the difference of weight density between these materials, adoption of B_4C for the neutron shielding material is very effective in reducing the thickness and weight of FBR shielding. In spite of the big effect of neutron slowing down, graphite shows less attenuation performance than B_4C because of its small absorption cross section.

The prediction accuracy for each single layer material was compared in **Fig. 4**, using the C/E ratios of the Bonner ball responses obtained by DOT3.5 or DORT code and JSDJ2 library corresponding to the attenuation rate of the responses.

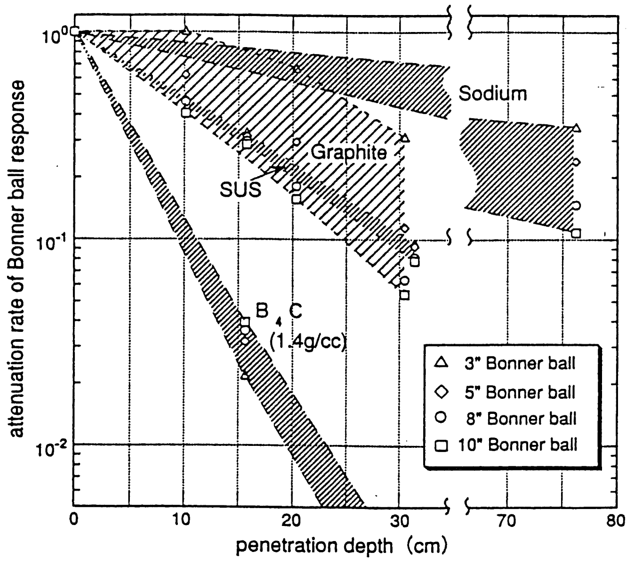


Fig. 3 Comparison of attenuation abilities

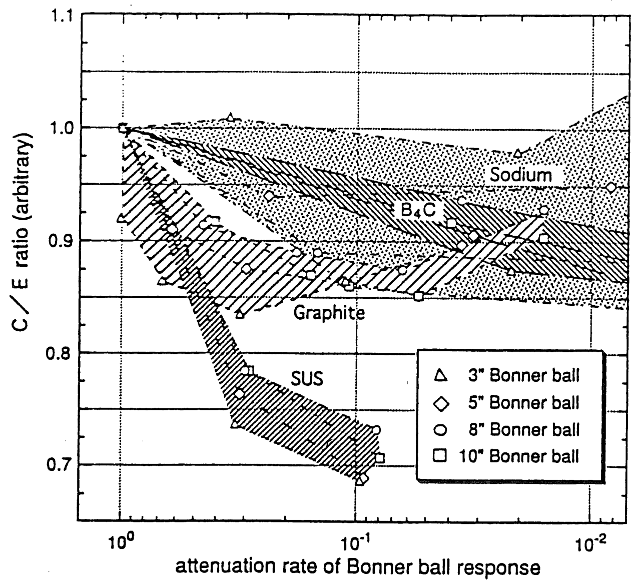


Fig. 4 Comparison of prediction accuracies

In this figure, the C/E ratios are normalized in the same way as in the attenuation performance. The C/E ratios roughly decrease in the order of B_4C, sodium, graphite and stainless steel. Omitting the C/E ratios of the 3" Bonner ball response, the variance of C/E ratios between Bonner balls of different diameters is relatively small for B_4C, graphite or stainless steel. This suggests good prediction accuracy of spectrum in these materials. On the contrary, larger variances are shown in sodium.

As the analytical results, C/E ratios for multi-layer mockup geometry are also obtained (not showed in this paper).

2. Fission Gas Plenum Experiment

Streaming factors; 0.95~1.07 are obtained from measured data of the Fission Gas Plenum experiment. It was concluded from the results that streaming effect in gas plenum region is negligible small. It is by the reason why the angular distribution of the incident neutron flux to the gas plenum region is not biased so much. This conclusion is confirmed by the related experiment[17] at YAYOI reactor in the university of Tokyo too.

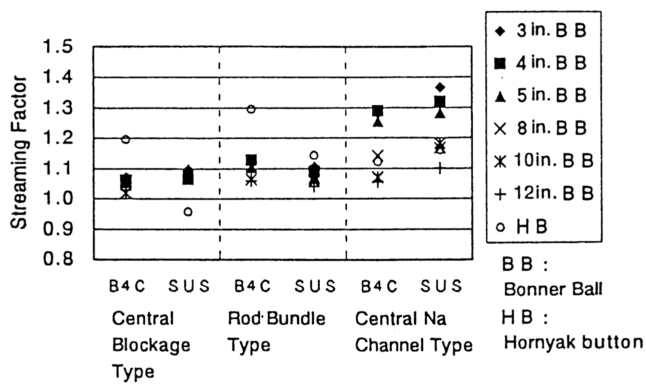
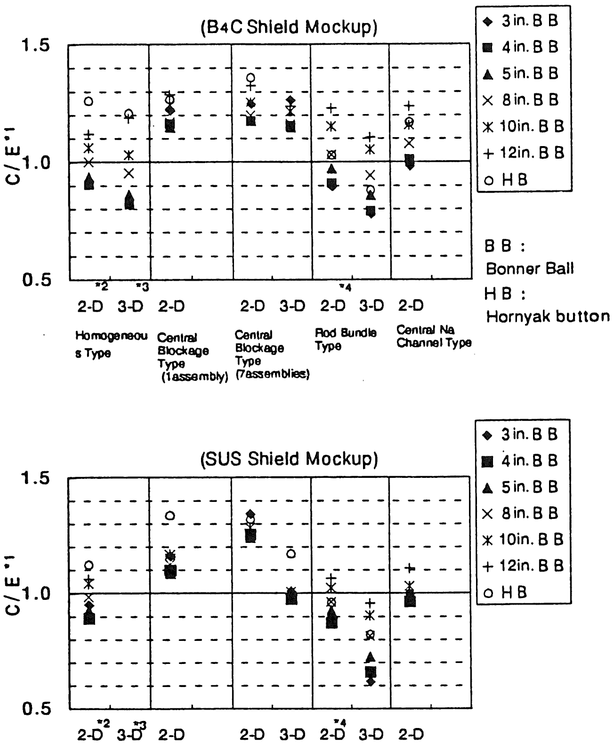


Fig. 5 Streaming factor on the central axis shield experiment obtained from measured data



*1 C/E values behind the axial shield configuration normalized by the experimental value preceding the configuration.
*2 2-dimensional Sn calc.
*3 3-dimensional Monte Carlo calc.
*4 homogeneous model calc.

Fig. 6 C/E values for axial shield experiment analysis

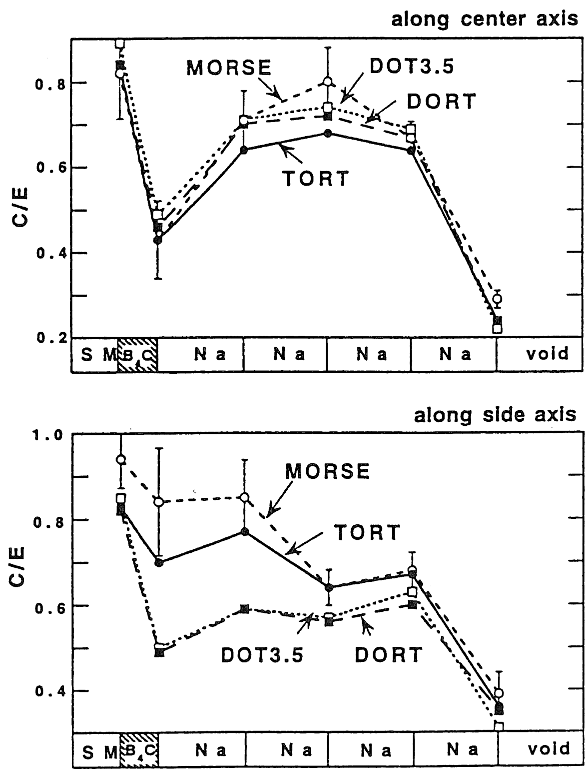


Fig. 7 Comparison of axial C/E distributions of sodium activation

3. Axial Shield Experiment

Figure 5 shows streaming factors of axial shields. The data are ratios of measured data of heterogeneous type mockups to homogeneous type mockup at the central axis. Maximum streaming factor is 1.4 of the central Na channel type assembly and streaming factor of other type assemblies is about 1.2. There is no remarkable difference in the streaming factors between B_4C and SUS shield. Therefore, effective streaming effect is not observed and two-dimensional calculation by homogenized model can be applied to design analysis by considering a little correction.

Figure 6 shows C/E ratios at the central axis. C/E ratios by two-dimensional analysis are 0.8~1.4, almost same in both B_4C and SUS configurations. The discrepancy between two and three-dimensional calculation is only 10~20% in any type mockups. Therefore, it was found out that penetration neutron flux even in the Rod Bundle type mockup which is hard to be evaluated by a two-dimensional model can be also predicted by two-dimensional calculation with same accuracy as other type mockups in the case of such multi pin rods bundle type mockup.

4. Intermediate Heat Exchanger Experiment

The axial distributions of C/E ratios of sodium activation in the IHX mock up region are compared for different analysis methods in **Fig. 7**. For this comparison, calculated results are normalized to the result of DOT3.5 at the location where the three dimensional calculation was started. Good agreements are shown between DOT3.5 and DORT analyses, and also, considering the statistical errors of the Monte Carlo analyses, agreement are also shown between MORSE and TORT analyses.

Comparing two and three-dimensional analyses, similar distributions of C/E ratios are obtained on the central axis, while apparent differences are observed along off-axis. Considering the agreement of C/E ratios on the central axis between two and three-dimensional calculations, it is concluded the two dimensional calculations give proper C/E ratios on the central axis.

Using the results of two-dimensional analyses, the C/E ratios at near the peak location of sodium activation, that is corresponding to the gap behind the first sodium slab, are selected and normalized with the C/E ratios at the entrance of B_4C front shield. Thus the normalized C/E ratios ranging between 0.8 and 1.03 are obtained in order to evaluate the

Table 2 C/E values for gap streaming experiment

Gap Width		1cm	3cm	2cm	2cm
Offset		No	No	4cm	8cm
C/E values of Hornyak Button Responses at Peak Positions	South side	1.10	1.19	0.90	1.05
	North side	0.89	1.08	0.83	1.00
Streaming Factor *		100	500	4	3

* Streaming factor is defined by the ratio of peak response and bulk penetration response.

correction factor for the uncertainty of the sodium activation in design analysis.

5. Gap Streaming Experiment

Table 2 shows the C/E ratios of Hornyak button responses at peak position for various gap types. The C/E ratios range between 0.8 and 1.2 including the non-symmetry of measured data. Although streaming factors for each gap type differ significantly, the C/E ratios do not vary a lot. Thus, it is verified that the streaming calculation with two-dimensional Sn code is accurate enough to be applied in design analysis.

V. Review of the Results

The analytical results were reviewed from the view point of the applicability to shielding design of the DFBR.

Generally, incident neutron sources to the mockups are well modeled with neutron energy spectrum of actual FBR plant by using UO_2 slabs or sodium tank as a spectrum modifier.

The accuracy of neutron penetration calculations through the major materials of FBR were obtained from the Radial Shield Attenuation experiment. Especially, high accuracy of B_4C which will be planned to be utilized as a shield material of the DFBR but was deficient in data so far was confirmed. In addition, the data of the multi-layer configurations which represented the actual radial shield of the DFBR are also obtained. It is expected that correction factors for penetration calculation will be reduced in the shielding design of the DFBR.

It was found out from the measured data of the Fission Gas Plenum experiment that streaming effect is negligible. This suggests angular distribution of incident neutron to the gas plenum, which is located just close to the core, is considered to be isotropic. Therefore, correction for streaming in gas plenum region is not necessary in penetration calculation by two-dimensional homogenized model.

In the Axial Shield experiment, since the overall geometry of the experiment is a honey comb shaped to mockup fuel assemblies and each of three geometrical types of shield rod with B_4C or SUS as a shield material is installed inside the honey comb, the experimental configuration is geometrically well-modeled with the actual axial shields. Therefore, the data can be utilized for evaluating the accuracy of the analytical method which calculate the streaming factor for an axial shield region.

In the Intermediate Heat Exchanger experiment, sodium activities were directly measured by irradiated sodium capsules. Therefore, it is expected that the analytical results of the experiment will be utilized as a data for evaluating the accuracy of sodium activity calculation after B_4C penetration. However, the difference of the incident neutron flux distribution to the IHX between in the actual design and in the experiment and, the effect of the sodium slab transformation should be taken into careful consideration to apply the analytical results to the design evaluation.

In the Gap Streaming experiment, the data for three types of annular gap widths and straight/offset slit are obtained. But the method how to apply the analytical results to the design evaluation should be studied because following differences are found in between the actual design and the experiment.

		(design/experiment)
(a)	Incident spectrum	soft/hard
(b)	Outlet shield	yes/none
(c)	Sn quadrature	S117/S166
(d)	Code	DOT3.5/DORT&DISKTRAN

VI. Conclusion

The analytical results of the JASPER experiment performed to resolve the problem with the shielding design of the DFBR are summarized in this paper, based on the results of a joint study between PNC and the Japan Atomic Power Company (JAPC). Both characteristics for bulk shielding attenuation and streaming of neutron though configurations consisting of several materials including B_4C, stainless steel, sodium and etc. were clarified and the analysis accuracy confirmed. Useful information to evaluate the shielding design accuracy of large FBR is accumulated. It is expected that shielding design margin of the DFBR will be reduced and cost reduction will be attained by making better use of the information.

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